CHAPTER 1. INTRODUCTION

The National High Magnetic Field Laboratory (NHMFL) entered its second decade of operations and exploration in year 2000. Much of the year was spent preparing for the next five-year renewal proposal review, 2001-2005, for the National Science Foundation. A renewal site review was held at the laboratory in Tallahassee on April 16-18. The NHMFL was extremely pleased to have several distinguished scientists, users, and collaborators speak to the review committee, including:

- Horst Störmer, Columbia University and Lucent Technologies, who spoke on high magnetic field science opportunities in semiconductors and quantum wells;
- Warren Warren, Princeton University, who discussed his perspectives on the next very exciting frontiers in high field NMR science;
- Dante Gatteschi, University of Florence, who talked about research opportunities in high field EMR;
- Jan Kees Mann, Director, High Field Magnet Laboratory, University at Nijmegen, The Netherlands, who addressed magnet technology collaborations with NHMFL;
- William J. Simonsick, Jr., Director, Mass Spectrometry, DuPont Performance Coatings, Marshall R&D Laboratory who commented on interactions in the field of ion cyclotron resonance;
- George Srajer, Experimental Facilities Division, Advanced Photon Source, Argonne National Laboratory who discussed joint magnet development activities for a unique research magnet;
- Steve McQuillan, Managing Director, Oxford Instruments Research Instruments, who commented on joint R&D efforts on high temperature superconductors; and
- Phil Ingram, President, Training Solutions Interactive, who addressed joint collaborations on science curriculum development for K-12 grades.

> Many achievements justify the view that the Lab is now the premier high magnetic field laboratory world wide...This ranking is based on achievements in several areas, first of all in its construction of magnets having significantly higher fields than are available elsewhere. The NHMFL has constructed the highest purely resistive DC field (33 T), the highest DC field (44 T) in a hybrid magnet, the highest long pulse field (60 T), and the highest short pulse field (79 T) magnets...The user program is developing well in many areas. The education outreach program is exceptionally strong, reaching out very effectively to K-12, to teachers, to the public, and to diverse undergraduate and graduate students. An in-house research program that takes strong advantage of the NHMFL facilities, helps Laboratory staff be responsive to new opportunities and give flexible support for new faculty and high-payoff ideas is also operating well.
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> **NSF site review committee report**

In addition, the chairs of the NHMFL's two principal advisory boards met with review officials: External Advisory Committee Chair George Crabtree of Argonne National Laboratory and Users Committee Chair Chuck Agosta of Clark University. Florida Lieutenant Governor Frank Brogan and Vice Chancellor James Mau of the State University System spoke to the continued support and commitment of the NHMFL.

Leaders of the three participating institutions—representing Florida State University, President Sandy D'Alemberte; the University of Florida, Vice President for Research Win Phillips; and Los Alamos National Laboratory, Program Director Allen Hartford—also spoke to the NSF site review panel about their respective commitments to the multidisciplinary laboratory.

Later in the year, the National Science Board approved a $117.5 million grant for the NHMFL through 2005. The award represents a 35 percent increase over the last five-year grant period of $87.5 million. NSF Director, Dr. Rita Colwell, praised the laboratory in her funding recommendation to the NSB: *The NHMFL requires this level of investment to maintain and consolidate its position of innovation and world leadership for research in high magnetic fields and magnet technology.*

User activity at the NHMFL for the year 2000 has produced 295 research reports. The research is broadly distributed across sixteen disciplines, with the largest number of projects being biology (47), magnetism and magnetic materials (36), chemistry (27), semiconductors (27), basic superconductivity (26), kondo/heavy fermions (19), molecular conductors (19), and magnetic resonance techniques (19). International users continue to constitute almost 40 percent of all users at the DC and Pulsed Field Facilities.

Magnets are complex systems of engineering and materials technology, and these state-of-the-art magnet systems are operated on the edge of their ultimate design limits as the laboratory tries to offer the extremes of magnetic fields to its diverse user community. An aspect of the

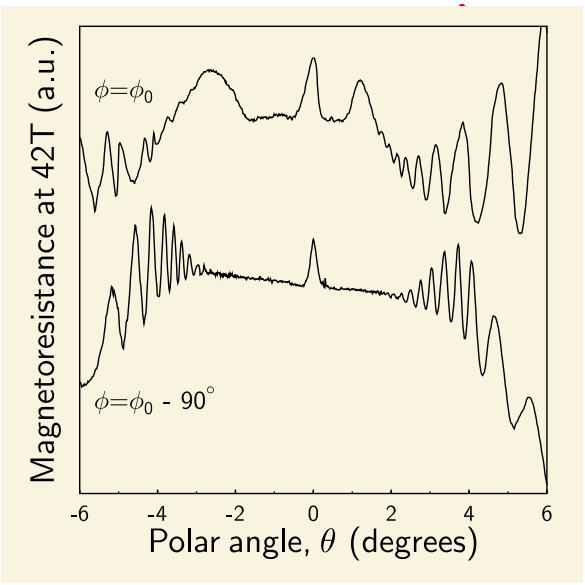
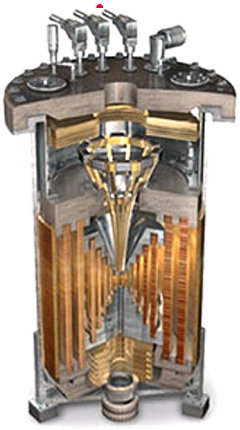


Figure 1. κ-$(BEDT\text{-}TTF)_2Cu(NCS)_2$ as a function of the applied magnetic field orientation. The peaks around θ=0 degrees in the two graphs demonstrate that the electron wave functions are coherent in all directions.
–A. Ardavan, J. Singleton, et al., personal communication.

design and operation of these systems includes a risk and lifetime assessment. Regrettably in the commissioning and operation of these systems unanticipated mishaps and failures do occur.

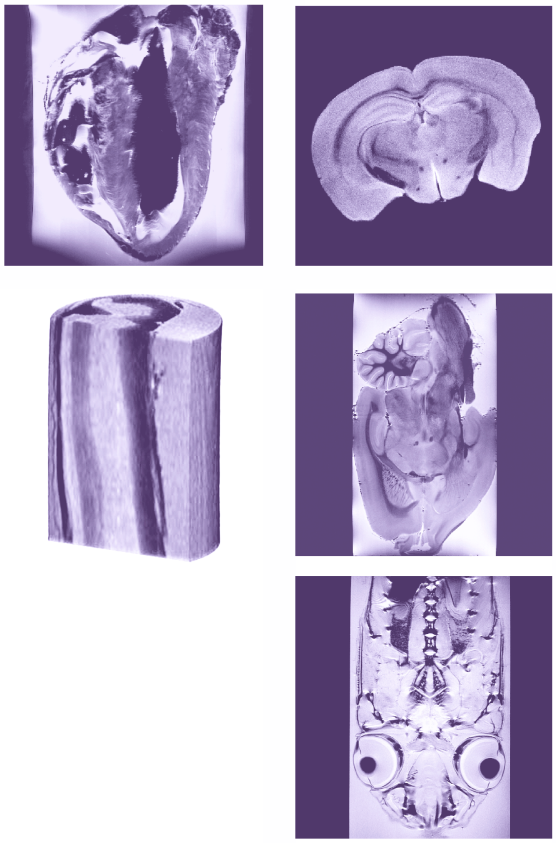
The commissioning and testing of the 45 T Hybrid magnet began early in the year and the Hybrid reached 45.1 T in late June. Unfortunately, the quench protection system failed during a routine testing run. The Hybrid magnet experienced some damage to one of the superconducting coils and could be operated safely only at lower fields. It ran at 37 T through the early fall, and at 42 T for the last half of December. New discoveries and interesting physics have already emerged from this system supporting the contention that if you expand parameter space new science will be found. Improvements in the resistive insert were already contemplated and when implemented in early 2001 should bring the central field back to its design specifications of 45 T. (note added in proof: The insert field was boosted still further in late January as a test. The total field was 45.1 T, and the insert's behavior during a day and half of normal use at 45 T leads to the expectation that users can count on 45 T throughout 2001.) Rebuild and eventual replacement of the innermost superconducting coils for the Hybrid superconducting magnet will be undertaken in 2001 so the Hybrid outsert can operate at its design field of 14 T, rather than the present operational restrictions, which allow only 11.2 T. With repair of the innermost superconducting coil and the implementation of modifications to the resistive insert, the laboratory will be able to provide fields beyond 45 T. This magnet had been designed with the eventual target of 50 T and moving to this target is one of the goals of the laboratory for the next five years. One of the unanticipated surprises of the 45 T Hybrid system recently pointed out by condensed matter science NMR users of the magnet is the high homogeneity of the magnet, which has accelerated interest in the system for such measurements.



From September 1999 through April 2000, the NHMFL Pulsed Field Facility worked very hard to move into a new and much improved experimental hall. This relocation doubles the capacity over the old building and provides magnet stations for the many magnet design strategies and experimental techniques currently under development. The long-pulse

and short-pulse user programs are now located in separate buildings and, for the first time, short-pulse experiments can operate completely independently of one another. The new facilities greatly enhance the laboratory effectiveness in responding to the challenges of a growing demand for these facilities.

At the NHMFL Pulsed Field Facility at Los Alamos, the unique 60 T Long-Pulse magnet has proven to be a unique tool for experimentalists. During its one and a half year of operations, a *Nature, Science*, and six *PRL* reports have been published utilizing the unique system. Unfortunately, the magnet failed during otherwise normal operations. Analysis of the magnet debris is ongoing and we believe the precise cause of the failure can be determined. The emerging theory is that the magnet failure nucleated as a stress-induced failure of the Nitronic-40 reinforcing shells in the middle layers of the magnet due to a recently discovered embrittled phase which can arise during thermal aging of Nitronic-40. The 60 T Long-Pulse magnet will be rebuilt during the next two years. User activity is being directed to other pulsed magnets including the newly-designed 50 T Mid-Pulse magnet, which will address many of the needs of the NHMFL Optics Program, which had constituted much of the research on the 60 T Long-Pulse. In addition, the 50 T Mid-Pulse magnet will also provide a platform for developing new experimental capabilities, such as AC specific heat and thermal conductivity measurements, as well as new low-noise magnetotransport measurements.

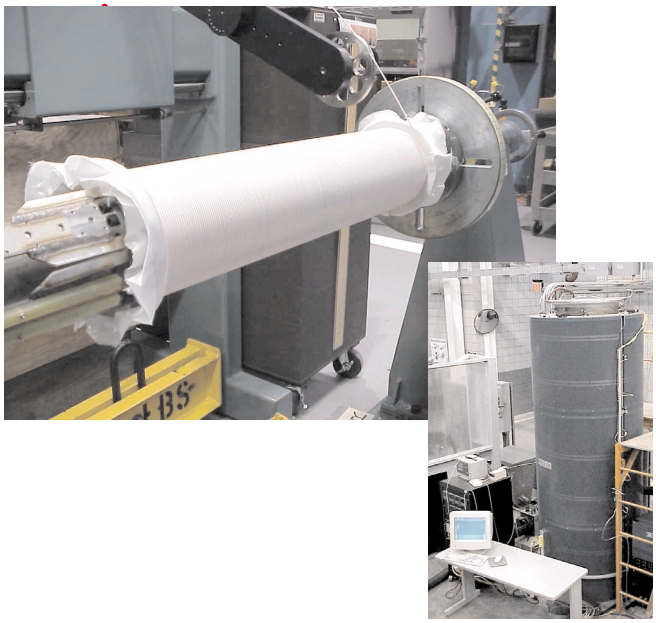


The Advanced Magnetic Resonance Imaging and Spectroscopy (AMRIS) facility at the University of Florida McKnight Brain Institute has experienced a very active and productive year. The Bruker 750 MHz wide bore NMR/MRI system was delivered and installed. This is the first 750 MHz wide bore NMR system installed by Bruker in the United States and the second in the world. This new system has imaging capabilities and has been producing high quality images. AMRIS has been busy getting the state-of-the-art 11.7 T, 40 cm wide bore MRI magnet tested and operational. At this time, the magnet is operating safely at 9.4 T and will soon be

brought to its design field of 11.7 T. The first *in vivo* images of a rat are quite impressive. During 2000, AMRIS group submitted an NIH Resource proposal and was site visited at the end of the year. The site visit report was extremely positive and AMRIS is awaiting the official NIH response.

The NSF renewed its support for the NHMFL's National High-Field Fourier Transform Ion Cyclotron Resonance Mass Spectrometry (FT-ICR MS) Facility for a second five-year period, 2000-2004. The NSF chose to fund the proposal at its full requested budget of $5.76 million. **The ICR program has been one of the shining successes of the NHMFL both in terms of instrumentation and technique development and in applications for a worldwide user base.** As the end of this funding approaches, the continued support of this unique facility will be transferred to the NSF core grant and funding for this facility in year 2004 and 2005 has already been incorporated into the $117.5 million funding of the core activities of the laboratory.

A consortium of scientists from NHMFL, FSU, FAMU, and UF under the leadership of Professor Peter Fajer has received a $1.1 million grant from the NSF to acquire a high field EPR spectrometer. This state-of-the-art spectrometer is the first instrument of its kind in the United States and is capable of high field/frequency (9 and 94 GHz) operation, pulsed (Fourier Transform) operation, and pulsed Electron-Electron Double Resonance (ELDOR) and Electron Nuclear Double Resonance (ENDOR). The spectrometer will support a wide range of important research topics and is consistent with the laboratory's commitment to multi- and cross-disciplinary activities.



The 900 MHz, 100 mm wide bore NMR magnet system is a major part of the long-term program to provide user access to high resolution NMR at and beyond 25 T. The program is a collaboration between the NHMFL and the principal industrial partner Intermagnetics General Corporation (IGC). Additional industrial suppliers include Supercon, Vacuumschmelze, and Ability Engineering and Technology. The main components of the 900 MHz have all been fabricated at three locations simultaneously. IGC fabricated all of the NbTi coils at its

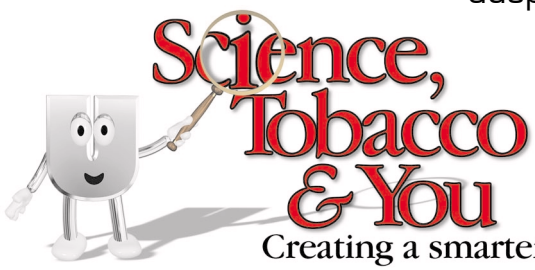
main facility located in Latham, New York, and Ability Engineering built the cryostat in South Holland, Illinois. The NHMFL fabricated and impregnated all the Nb_3Sn coils as well as coordinating the overall assembly logistics and final assembly design. **Commissioning of the 900 MHz wide bore is expected in the fall of 2001.**

The In-House Research Program completed its fifth year of competitive solicitations. The program is designed to encourage collaborations between internal and external investigators, and supports bold and often risky efforts that have the potential to expand the realm of high magnetic field research or open new frontiers. The program provides seed money to explore new opportunities or develop new capabilities for the user programs at the laboratory. Funding from this program is limited to two years and extensions beyond this two-year limit require external funding. The leadership of this program rotates among the three institutions and this year Dr. Al Migliori, NHMFL of Los Alamos National Laboratory, assumed these duties. The 2000 solicitation moved to a pre-proposal process that was reviewed by the Research Program Committee augmented by members of the NHMFL Users Committee, who are elected by NHMFL external users. Pre-proposals deemed to hold the highest merit were then passed on to the second review step as full proposals. This year 46 pre-proposals were submitted, 18 proceeded to full proposal status, and 6 proposals were ultimately funded for a period of two years.

The U.S. Office of Naval Research awarded Florida State University $10.9 million over three years to establish a program in advanced power systems that will support the Navy's all-electric ship program. In announcing the award at the NHMFL, Admiral Jay Cohen, Chief of Naval Research, compared the switch to the all-electric ship to the historic transition from sails to steam powered ships. **The program will be conducted by FSU's Center for Advanced Power System (CAPS), which is focused on research and development of advanced electrical power systems for transportation and utilities.** The center builds on the expertise of the NHMFL in high field electromagnetics, materials, and superconductivity, FSU, and FAMU-FSU College of Engineering. All three have unique resources for the development of new equipment and systems for electrical power applications and for training the next generation of electrical power system

engineers. The center is dedicated to developing a multidisciplinary research program with a strong partnership between government, industry, and the academic research community. “Recent developments in superconductivity, magnetics, solid state power switching and control give power system engineering a whole new range of options to work with,” said James Ferner, interim director of CAPS. “We are on the edge of a revolution in electrical power engineering.”

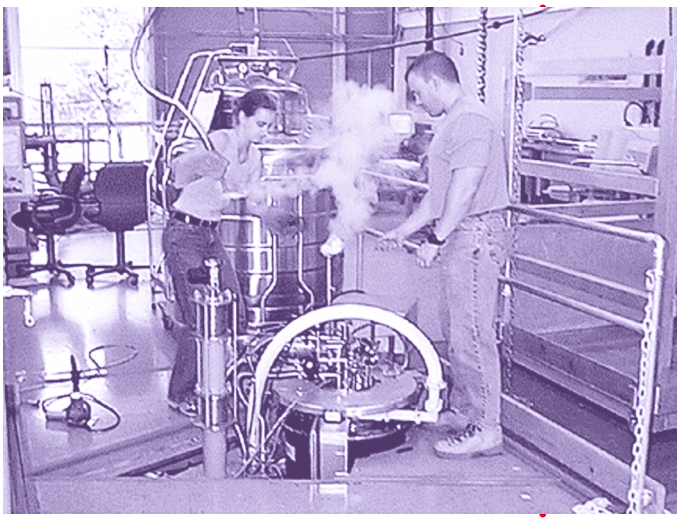
In support of the ongoing educational mission of the NHMFL, the Center for Integrating Research and Learning (CIRL) continued its expansion of educational programs, creating new classroom resources, extending further its education opportunities for students and teachers, and developing new programs. CIRL saw an increase in national interest with the *Science, Tobacco & You* curriculum program now adopted in two states outside of Florida—Connecticut and Illinois. As many as a 1,000 Connecticut fourth and fifth grade teachers returned to their classrooms this fall with digital cameras, CD-ROMS, stethoscopes, lungs bags with mouthpieces, stopwatches, and other tools and knowledge to teach students how the body works and the effects of tobacco on the body.



The CIRL once again hosted talented teachers and undergraduates in the Research Experiences for Teachers program and the Research Experiences for Undergraduates summer internship program. An essential part of both programs is combining research with presentation skills and events that encourage communication and collaboration among groups. Sixteen participating teachers presented their work in a public showcase of materials they created to translate their research experiences into classroom activities. The showcase, combined with written reports, gave teachers an opportunity to articulate what they had learned about the process of science, magnets and related content material, and science

education. One elementary teacher said, “My vision of science has been enhanced through the work I did with my mentor and sharing of experiences we had with other groups.” Another teacher remarked, “Due to my experience here at the NHMFL, I really want to turn my students on to science.”

The NHMFL hosted the seventh Research Experiences for Undergraduates and 21 students selected from across the country spent eight weeks in research mentorships at all three sites. In addition, CIRL was asked to incorporate ten other interns from FSU into the program. The breakdown of participants was 76 percent women and 24 percent men. The students’ research experiences were in biology, chemistry, geochemistry, engineering, and physics.



The National Science Foundation challenged the NHMFL from its inception to reach out to other organizations in order to support and develop a wide range of new magnet technologies. To this end, the NHMFL has worked aggressively to engage private industry, other federal agencies and institutions, and international organizations. These outreach activities have gained momentum each year and have had a profound effect on the NHMFL’s ability to maintain worldwide leadership in high magnetic field research and technology. This year, collaborations with the private sector grew about 30 percent. The laboratory is also engaged in significant collaborations with almost all of the Department of Energy national laboratories and is working with the Office of Naval Research on a long-term research and development program for the electrification of naval ships. Bilateral science and technology collaborations are among the most unifying forces between national and international organizations and the number of these affiliations is rising as well.